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**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

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Harald BOTHE et al.

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For: PATTERN SEQUENCE SYNCHRONIZATION

**CLAIM FOR PRIORITY UNDER 35 USC § 119**

Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

September 9, 2003

Sir:

The benefit of the filing dates of the following prior foreign application filed in the following foreign country is hereby requested for the above-identified patent application and the priority provided in 35 U.S.C. §119 is hereby claimed:

**European Patent Application No. 03015374.6 filed on July 8, 2003 in Europe**

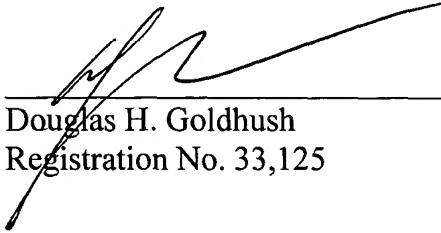
In support of this claim, certified copy of said original foreign application is filed herewith.

It is requested that the file of this application be marked to indicate that the requirements of 35 U.S.C. §119 have been fulfilled and that the Patent and Trademark Office kindly acknowledge receipt of these/this document.



Please charge any fee deficiency or credit any overpayment with respect to this paper to Counsel's Deposit Account No. 50-2222.

Respectfully submitted,



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**Patentanmeldung Nr.    Patent application No.    Demande de brevet n°**

03015374.6

Der Präsident des Europäischen Patentamts;  
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**Sheet 2 of the certificate**  
**Page 2 de l'attestation**

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TITLE OF THE INVENTION

Pattern Sequence Synchronization

5 FIELD OF THE INVENTION

The present invention relates to a method and an apparatus for pattern sequence synchronization between a first and a second pattern sequence. In particular, the invention relates to a  
10 synchronization between a received pattern sequence which may be generated at a transmitting device and a reference pattern sequence of a receiving device. The invention is applicable in single carrier transceivers with frame synchronization for pilot detection, in single carrier quadrature direct  
15 conversion transceivers for single carrier detection, and in OFDM (Orthogonal Frequency Division Multiplexing) systems for finding training sequences.

BACKGROUND OF THE INVENTION

20

Frame synchronization is often used to enable further blocks and error correction loops in a receiver chain. The reference pattern sequence known at the receiver and synchronized by a pilot detection and synchronization scheme gives necessary  
25 information to receiver data aided error detector loops for improving the receiver performance.

In continuous transmission based systems it is necessary to have an extremely signal distortion tolerant architecture. One  
30 of the major errors is the transmitter/receiver carrier-frequency mismatch.

Synchronization of a reference pilot symbol sequence with a pilot symbol sequence in received data is done in the prior  
35 art by correlation of IQ symbols of the received pattern

sequence with the reference pattern sequence of pilot symbols, which procedure is also called Pilot Vector (PV) correlation procedure.

In the following description of the conventional PV

5 correlation procedure it is assumed that there is no frequency mismatch between the transmitter and the receiver.

The correlation is running permanently on the received pilot symbols. For each received pilot symbol  $s(n)$  the correlation is done on the last "Z" received symbols ( $s(n)..s(n-Z)$ ) with  
10 reference pilot symbols ( $r(1)..r(Z)$ ).

$$s(n) = s_I(n) + js_Q(n) = |s(n)| \cdot e^{j\varphi_s(n)}; \quad r(k) = r_I(k) + jr_Q(k) = |r(k)| \cdot e^{j\varphi_r(k)}; \quad (1)$$

$$\begin{aligned} corr_{PV}(n) &= \sum_{k=1}^Z s(n-k) \cdot r^*(Z-k) \\ corr_{PV}(n) &= \sum_{k=1}^Z |s(n-k)| \cdot |r(Z-k)| \cdot e^{j(\varphi_s(n-k) - \varphi_r(Z-k))} \end{aligned} \quad \begin{array}{l} Z: \text{ Search Sequence Length} \\ (2) \end{array}$$

Assuming no imperfections, if the reference pattern sequence matches with the received pattern sequence of pilot symbols and " $|s(n)| = |r(k)| = a$ ", the correlation output  $corr_{PV}$

15 results to:

$$corr_{PV}(n) = \sum_{k=1}^Z a \cdot a \cdot e^{j(0)} = Z \cdot a^2 \quad (3)$$

The analog stages of a transceiver system introduce unwanted imperfections like transmitter/receiver carrier-frequency and phase mismatch. The higher the carrier-frequency the higher  
20 the impact to transmitter and receiver carrier-frequency mismatch will be. Especially, during system start-up process an extended mismatch is expected. The receiver has to be able to detect and correct these effects in the widest range as possible. The carrier-frequency mismatch is seen as an

25 incremental phase shift ( $n\Delta\theta$ ) on received IQ symbols  $s(n)$ .

$$s(n) = |s(n)| \cdot e^{j\varphi_s(n)} \cdot e^{jn\Delta\theta}$$

The conventional method is to correlate the received IQ symbol  
5 pattern sequence with a reference pattern sequence of pilot  
symbols. This approach is rather sensitive to carrier-  
frequency mismatch because each correlation product is  
infected by the mismatch seen as IQ symbol rotation ( $0..n\Delta\theta$ ).  
The correlation products calculated over the complete pattern  
10 sequence length are summed up. Finally, the impact of the  
carrier frequency mismatch distorts the correlation result  
significantly.

As mentioned above, a carrier mismatch has a significant  
15 effect to the above-described pattern sequence correlation. In  
case the carrier mismatch exceeds a certain range the  
correlation does not deliver the necessary periodic maximum  
peaks. Consequently, the exact position of the pilot sequence  
and the framing will not be found. Furthermore, frame  
20 dependent working blocks as well as detection blocks, which  
work on reference and received pilot symbols, will not get the  
necessary inputs. Finally, the receiver does not get into the  
"lock" status, as the pilot sequence is not found.

25 In other words, in case the conventional frame synchronization  
method is used the digital receiver is unable to start-up  
above a threshold of mismatch. The prior art correlation based  
frame synchronization techniques tolerate this carrier-  
frequency offset only up to a certain limit, since the impact  
30 of the carrier frequency mismatch distorts the correlation  
result significantly.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to increase the tolerable range of carrier-frequency mismatch.

5

According to the invention, this object is achieved by a method according to claim 1, an apparatus according to claim 9, a system according to claim 14, as well as a computer program product according to claim 18.

10

The present invention uses differential phase information included in a pattern sequence of symbols for correlation. Compared with prior art techniques, the following advantages can be achieved:

15

- at a digital receiver input, a much higher carrier-frequency mismatch is tolerable up to which the pilot detection is able to work;

20

- in the pattern sequence synchronization, as one result of the correlation the constant carrier-frequency mismatch is obtained;

- a pilot symbol generation at the receiver is improved;
- fast carrier-frequency and phase error detectors work on worse mismatch ranges which can be derived directly out of the correlation procedure according to the present invention; and

25

- detectors working on received and reference pilot symbols get improved inputs at a worse carrier mismatch.

## BRIEF DESCRIPTION OF THE DRAWINGS

30

Fig. 1 shows a flow diagram illustrating a method of synchronizing with a pattern sequence according to the present invention.

Fig. 2 shows a schematic block diagram illustrating an apparatus for synchronizing with a pattern sequence according to the present invention.

5 Fig. 3 shows a block diagram of a single carrier system comprising a pilot detection principle according to an embodiment of the invention.

10 Fig. 4 shows a constellation diagram of TCM 32 modulated data symbols and QPSK modulated pilot symbols.

Fig. 5 shows an IQ data stream framing realized by a periodically inserted predetermined pattern sequence of pilot symbols according to an embodiment of the invention.

15

Fig. 6 shows a block diagram of a pilot position observation block according to an embodiment of the invention.

20 Fig. 7 shows a pattern sequence of pilot symbols including a reference pattern sequence.

Fig. 8 shows a constellation diagram illustrating ideal QPSK modulated pilot symbol positions.

25 Fig. 9 shows a constellation diagram illustrating rotated pilot symbol positions due to a carrier-frequency mismatch.

Figs. 10 to 12 show constellation diagrams illustrating a correlation technique according to the prior art.

30

Figs. 13 to 18 show simulation results.

#### DESCRIPTION OF THE INVENTION

Fig. 1 shows a flow diagram illustrating a method of synchronizing a first pattern sequence and a second pattern sequence according to the invention. In step S11, symbols  $r(k)=r_I(k)+jr_Q(k)$  of a first pattern sequence are correlated, which first correlation step yields a first differential phase information sequence  $\alpha_r(k)$ . In step S21, symbols  $s(n)=s_I(n)+js_Q(n)$  of a second pattern sequence are correlated, which second correlation step yields a second differential phase information sequence  $\alpha_s(n)$ . In step S13, the first and second differential phase information sequences are correlated, which third correlation step yields a correlation result  $\text{corr}_{\text{DPV}}(n)$ . Finally, in step S14, a synchronization between the first and second pattern sequences is determined on the basis of the obtained correlation result.

Fig. 2 shows a block diagram illustrating a synchronizer 20 for synchronizing two pattern sequences according to the present invention. The synchronizer 20 comprises a first correlation block 21 for correlating symbols  $r(k)=r_I(k)+jr_Q(k)$  of a first pattern sequence and outputting a first differential phase information sequence  $\alpha_r(k)$ , a second correlation block for correlating symbols  $s(n)=s_I(n)+js_Q(n)$  of a second pattern sequence and outputting a second differential phase information sequence  $\alpha_s(n)$ , a third correlation block 23 for correlating the first and second differential phase information sequences and outputting a correlation result  $\text{corr}_{\text{DPV}}(n)$ , and a block 24 for determining a synchronization between the first and second pattern sequences on the basis of the correlation result.

The aim of the above described correlation technique is to find the absolute position of the first pattern sequence in the second pattern sequence. The correlation technique is based on the use of the differential phase information or

differential phase vector (DPV) sequences. The  $DPV\alpha_s$  is calculated out of a symbol  $s(n)$  of the second pattern sequence, which may be a currently received symbol  $s(n)$ , and a previous symbol  $s(n-1)$  of the second pattern sequence. The DPV  $\alpha_r(k)$  of the first pattern sequence is calculated out of a symbol  $r(k+1)$  and a symbol  $r(k)$ .

$$\begin{aligned}\alpha_s(n) &= s(n) \cdot s^*(n-1) = |s(n)| \cdot |s(n-1)| \cdot e^{j(\varphi_s(n) - \varphi_s(n-1))}; \\ \alpha_r(k) &= r(k+1) \cdot r^*(k) = |r(k+1)| \cdot |r(k)| \cdot e^{j(\varphi_r(k+1) - \varphi_r(k))};\end{aligned}\tag{4}$$

with  $\Delta\varphi_s = (\varphi_s(n) - \varphi_s(n-1));$   
 $\Delta\varphi_r = (\varphi_r(n) - \varphi_r(n-1));$

The number of first DPVs is one less than a length  $Z$  of the first pattern sequence of symbols.

$$corr_{DPV}(n) = \sum_{k=1}^{Z-1} \alpha_s(n-k) \cdot \alpha_r^*(Z-1-k);\tag{5}$$

$$corr_{DPV}(n) = \sum_{k=1}^{Z-1} |\alpha_s(n-k)| \cdot |\alpha_r(Z-1-k)| \cdot e^{j(\Delta\varphi_s(n-k) - \Delta\varphi_r(Z-1-k))}$$

10

The third correlation is done on the last " $Z-1$ " DPVs of the second pattern sequence ( $\alpha_s(n) \dots \alpha_s(n-Z+1)$ ) and the first pattern sequence ( $\alpha_r(Z-1) \dots \alpha_r(1)$ ). Assuming no imperfections, in case the first and second pattern sequences match and

15 " $|s(n)| = |r(k)| = a$ ", the correlation results to:

$$corr_{DPV}(n) = \sum_{k=1}^{Z-1} a^2 \cdot a^2 \cdot e^{j(0)} = (Z-1) \cdot a^4\tag{6}$$

Thus, as can be seen from the equations (3) and (6), in ideal case the difference between the correlation techniques of the prior art and the present invention is seen as the power of

20 "a" only.



The second and third correlation steps may run permanently on the symbols of the second pattern sequence. For each symbol  $s(n)$  the second correlation is done on the last  $Z$  symbols  $s(n)..s(n-Z)$ . In other words, for each repetition  $m$ , the  
 5 symbols are shifted by one symbol so that  $Z$  symbols  $1+m$  to  $Z+m$  of the second pattern sequence are correlated two at a time.

In case of a carrier-frequency mismatch between the symbols of the first and second pattern sequences, e.g. due to a mismatch  
 10 between carrier-frequencies of a transmitter transmitting the second pattern sequence and a receiver receiving the second pattern sequence from the transmitter, the PV correlation technique result according to the prior art will decrease significantly. Fig. 8 shows ideal symbol positions, the  
 15 symbols being QPSK (Quadrature Phase Shift Keying) modulated according to an embodiment of the invention. Fig. 9 shows rotated symbol positions because of carrier-frequency mismatch. The mismatch  $\Delta f$  is seen on the symbols as a rotation by an incremental phase shift  $\Delta\theta$  on the second pattern  
 20 sequence, increasing symbol by symbol. In other words, compared to  $s(0)$ , the rotation of  $s(2) = 2 \cdot \Delta\theta$ .

$$\Delta f = f_{transmit} - f_{receiver}; \quad \Delta\theta = \frac{\Delta f \cdot 2\pi \cdot PS}{f_{symbol}}; \quad PS: \text{Symbol or Pilot Spacing} \quad (7)$$

It follows for  $s'(n)$  and the DPVs  $\alpha'_s(n)$  of the second pattern sequence in case of a carrier mismatch:

$$s'(n) = |s(n)| \cdot e^{j\varphi_s(n)} \cdot e^{jn\Delta\theta} \quad (8a)$$

$$\alpha'_s(n) = s'(n) \cdot s'^*(n-1) = |s(n)| \cdot |s(n-1)| \cdot e^{j\Delta\varphi_s(n)} \cdot e^{j\Delta\theta}; \quad (8b)$$

25

Thus, the symbol  $s'(n)$  is rotated by " $n\Delta\theta$ " (Eq.8a) and the DPV only by  $\Delta\theta$  (Eq. 8b).

For the correlation techniques according to the prior art and the present invention follows:

$$corr'_{PV}(n) = \sum_{k=1}^Z |s'(n-k)| \cdot |r(Z-k)| \cdot e^{j(\Delta\varphi, (n-k) + (n-k)\Delta\vartheta - \Delta\varphi, (Z-k))} \quad (9)$$

$$corr'_{DPV}(n) = \sum_{k=1}^{Z-1} |\alpha', (n-k)| \cdot |\alpha_r, (Z-1-k)| \cdot e^{j(\Delta\varphi, (n-k) + \Delta\vartheta - \Delta\varphi, (Z-1-k))} \quad (10)$$

In case pattern sequence matching is assumed and " $|s(n)| = |r(k)| = a$ " but with carrier-frequency mismatch it follows:

$$corr'_{PV}(n) = \sum_{k=1}^Z a^2 \cdot e^{j(n-k)\Delta\vartheta} \quad (11)$$

$$corr'_{DPV}(n) = \sum_{k=1}^{Z-1} a^4 \cdot e^{j\Delta\vartheta} = e^{j\Delta\vartheta} \cdot \sum_{k=1}^{Z-1} a^4 = (Z-1) \cdot a^4 \cdot e^{j\Delta\vartheta} \quad (12)$$

As can also be seen from Figs. 10 to 12, the PV correlation result  $corr'_{PV}$  is decreased in case of an incremental phase shift  $\Delta\vartheta$  with respect to  $corr_{PV}$  (Eq.5). Each term in the sum of  $corr_{PV}$  is infected by a higher phase shift. Fig. 10 shows a correlation product  $cv$  of first and second symbols  $n=2$ , Fig. 11 shows correlation products  $cv(0..2)$  of three consecutive first and second pilot symbols, and Fig. 12 shows a correlation vector  $corr_{PV}$  sum of  $cv(0)$  to  $cv(2)$ .

15

Compared thereto, the  $corr'_{DPV}$  result according to the invention with carrier-frequency mismatch is rotated only by one phase shift  $\Delta\vartheta$  (Eq.6).

20 Because of less implementation effort the correlation result will be taken as squared real plus imaginary part:

$$|corr'_{PV}(n)|^2 = \left| \sum_{k=1}^Z a^2 \cdot e^{j(n-k)\Delta\vartheta} \right|^2 \quad (13)$$

$$\begin{aligned} |corr_{DPV}(n)|^2 &= \left| \sum_{k=1}^{Z-1} a^k \cdot e^{j\Delta\theta} \right|^2 = \left| e^{j\Delta\theta} \cdot \sum_{k=1}^{Z-1} a^k \right|^2 = |(Z-1) \cdot a^k \cdot e^{j\Delta\theta}|^2 \\ |corr_{DPV}(n)|^2 &= (Z-1)^2 \cdot a^8 \end{aligned}$$

(14,

The impact of carrier-frequency mismatch on the Pilot Vector (PV) approach correlation result of the prior art (Eq. (13)) is seen as significant decrease of the possible maximum value.

5 As shown in Fig. 11, each  $cv(n)$  is rotated more.

For the DPV correlation approach of the invention (Eq. (14)) the frequency error impact is removed totally. The absolute value of the DPV correlation result is not changed compared to the one without carrier-frequency mismatch. In addition to  
10 this the DPV correlation technique serves as carrier-frequency error detector. It delivers the phase information or phase angle of the correlation result  $corr_{DPV}$  as the constant carrier-frequency mismatch.

15 The symbols of the second pattern sequence may be contained in a data symbol stream and may be modulated in a different way from the data symbols in the data symbol stream and may be detected in the data symbol stream on the basis of the different modulation.

20

As mentioned above, the second pattern sequence may be received by a receiving device from a transmitting device, and the first pattern sequence, forming at least a part of the second pattern sequence, is known in the receiving device in  
25 which the first to third correlation steps are performed.

The transmitting device may include means for generating the symbols of the second pattern sequence, and means for transmitting the symbols of the second pattern sequence to the  
30 receiving device. Furthermore, the transmitting device may comprise first modulation means for modulating data of the

second pattern sequence according to a first modulation scheme, thereby providing the symbols of the second pattern sequence, a second modulation means for modulating payload data according to a second modulation scheme, thereby  
5 providing a data symbol stream, and means for inserting the symbols of the second pattern sequence into the data symbol stream.

In the following, an embodiment of the present invention will  
10 be described in which the correlation scheme of the invention is applied in a single carrier transceiver system with frame synchronization. However, the invention is not limited to single carrier transceiver systems but can be also applied in single carrier quadrature direct conversion transceivers for  
15 single carrier detection, and in OFDM systems for finding training sequences in case of frequency errors.

Fig. 3 shows a block diagram of a single carrier system with frame synchronization using pilot detection according to an  
20 embodiment of the invention. The framing is based on a periodically inserted pattern sequence of pilot symbols. Pilot detection is a key process in digital receivers and is responsible for the frame synchronization. The aim is to find the absolute position of a pattern sequence in received data.

25 As shown in Fig. 3, a Tx (transmitter) pilot generation block 44 in a transmitter generates a predetermined pattern sequence of pilot symbols. The generation is based on PRBS (Pseudo Random Binary Sequences) bit sequences and additional QPSK (Quadrature Phase Shift Keying) modulation. In other words, in  
30 block 44 the generated PRBS bit sequences are QPSK modulated and QPSK modulated IQ (In-phase, Quadrature-phase) pilot symbols are output. Thus, as shown in Fig. 4, the pilot symbols have all the same absolute amplitude value, but differ in phase relation by  $45^\circ$ ,  $135^\circ$ ,  $225^\circ$  and  $315^\circ$ . In a QAM

(Quadrature Amplitude Modulation)/TCM (Trellis Coded Modulation) modulation block 45, payload data is M-ary QAM or TCM modulated and M-ary QAM or TCM modulated IQ payload symbols are output.

- 5 In a pilot multiplexing block 46 the pilot symbols are inserted equidistantly into the IQ payload symbol data stream using adjustable but constant intervals PS (Pilot Spacing) between payload data symbols as shown in Fig. 5. The periodically included pilot symbol pattern sequence is used  
10 for framing of transmit or payload data, frame synchronization and detection of carrier-frequency and phase mismatches. The frame length is defined by the PRBS length and PS. Before a transmission via an antenna 50, the data stream is passed through a block 47 to be sampled up, interpolated, low pass  
15 filtered and up-converted to the carrier frequency.

- An Rx (Receiver) down-conversion block 52 in a receiver down-converts the IQ data stream received by an antenna 51, the received IQ data stream containing a payload and pilot symbol pattern sequence. In an ADC (Analog/Digital converter) input  
20 data are corrupted by certain errors like AWGN (Additive White Gaussian Noise), echo, carrier-frequency and carrier-phase mismatch, etc. In a block 54 errors in quadrature, balance, bias and gain as well as echos on IQ symbols are reduced. In a block 55 low pass filtering and down sampling follows.

- 25 IQ symbols input into a pilot detection block 40 are pre-corrected by a CMA (Constant Modulus Algorithm) adaptive equalizer and other non-data-aided correction blocks (not shown). The pilot detection block 40 is divided into two sub-blocks. The first sub-block is a PPO (Pilot Position  
30 Observation) block 41 which identifies the equidistant position of the pilot symbols on the received data stream.

The PPO block 41 identifies the equidistant position of the inserted pilot symbols (Pilot 1 - Pilot n) in the received

data stream using the known pilot spacing and knowledge of same absolute pilot symbol amplitude. Fig. 6 shows a block diagram of an embodiment of the PPO block 41. In block 62 the absolute value of symbols  $s(n)$  is calculated. Following block 5 62, a received symbol amplitude  $|s(n-PS)|$  delayed by the pilot spacing PS is subtracted from a current symbol amplitude  $|s(n)|$ , and subsequently in block 65 a minimum search is performed.

Because of the constant pilot symbol amplitude and uniformly 10 distributed data symbol amplitude, this subtraction  $|s(n)| - |s(n-PS)|$  results periodically in a minimum with PS distance. Taking the demultiplexing in block 63 with a selection by a counter 61 into account, the pilot position is given as the index of an accumulator 64 with minimum result. The robustness 15 of the PPO block 41 can further be improved by requiring N consecutive minimum positions to be identical.

The PPO block 41 marks the pilots in the data stream and enables a second sub-block, a Pilot Sequence Synchronizer PSS 42. In other words, if the pilot symbol position has been 20 found by the PPO block 41, the PSS 42 is enabled and the correlation procedure starts. The PSS 42 is the second sub-block of the pilot detection block 40, which synchronizes the received pattern sequence and a reference pattern sequence.

25 The task of the PSS 42 is to find the frame structure in the received data stream by correlation of the received pattern sequence (second pattern sequence) of pilot symbols with the in the receiver known reference pattern sequence (first pattern sequence) of pilot symbols according to the scheme 30 described in connection with Figs. 1 and 2 and equations (4) to (6). If the frame is found the PSS enables an Rx pilot generating block 43, which generates the same pattern sequence of pilot symbols as included in the transmitter. The generated

pilot symbol sequence is synchronized with the received data and can be used by following fast data aided error detector blocks 56 and 58. These blocks compare the generated pilot symbol pattern sequence with the received pilot symbol pattern sequence for further error calculations. After the fast corrections block 56, the data symbols are subjected to a QAM/TCM demodulation in block 57.

As described above the frame structure detection is done in the PSS 42 by correlation of the DPV (Differential Phase Vector) sequences calculated out of the received  $s(n)$  and reference  $r(k)$  pattern sequences of pilot symbols. The reference sequence of pilot symbols is not necessarily of the same length as the transmitted pattern sequence of pilot symbols as shown in Fig. 7. However it is required that the reference pattern exists only one time in the complete transmitted pattern sequence of pilot symbols to avoid multiple detection in one frame. The length  $Z$  of the reference pattern sequence is adjustable as well as a length  $P$  of the pattern sequence included in the transmitter.

As described in connection with equations (4) to (6), the DPV is given as conjugate complex multiplication of two consecutive pilot symbols. This will be done on the received pattern sequence of pilot symbols and the reference pattern sequence of pilot symbols. The permanently calculated DPV sequence of received data is correlated with the DPV sequence of the reference pattern sequence of pilot symbols. In case the received pilot sequence and the reference pattern sequence match, the absolute value of the DPV correlation results in a maximum. Frame detection is successful if this is detected in constant expected periodical distances. An internal state machine observes the number of the correct in periodical distance calculated maxima. In case the desired number of consecutive maxima is reached the following blocks (i.e.

blocks 43, 56, 57, 58 in Fig. 3) in the receiver chain are enabled.

5 In case of carrier-frequency mismatch of transmitter and receiver, which is one of the major errors in radio transceiver systems the DQPSK based pilot detection shows much higher robustness to this error than conventional techniques. Moreover, as can be seen from equation (12), the pilot detection block 40 delivers also the constant carrier-  
10 frequency mismatch as the phase angle of the correlation result. Based on synchronized received and reference pilots, the calculation of an IQ phase shift is enabled. Furthermore, data aided IQ amplitude error detectors are able to use this information. Possible error detectors are fast-carrier  
15 frequency, bias, quadrature, imbalance and intersymbol interference detectors.

As described above the correlation technique based on DPV (Differential Phase Vector) correlation is very robust to  
20 carrier-frequency error while maintaining good correlation and cross-correlation properties. The transmitter/receiver carrier-frequency mismatch has up to a certain limit nearly no impact on the DPV technique because of using pilot-to-pilot differential phase information. In the correlation result the  
25 error is seen only as phase shift. The absolute value, the correlation peak value, is not affected. The tolerable range of the carrier-frequency error is limited by the symbol rate input to the pilot detection block 40, the PS and the pilot-to-pilot ideal  $90^\circ$  phase shift only.

30

The correlation technique based on the DPV correlation can be implemented in an ASIC (Application-Specific Integrated Circuit) or as a software code in a DSP (Digital Signal Processor).

35



According to the present invention, a pattern sequence detection is improved by allowing a very high carrier-frequency mismatch compared with the conventional correlation technique. Moreover, the synchronization time for

5 synchronizing the first and second pattern sequences can be reduced. In particular, a pattern sequence detection of pilot symbols in a received data stream can be improved and the synchronization time of the whole receiver can be reduced.

10 In the following, simulation results derived from the conventional correlation technique and the DPV correlation technique according to the present invention are presented.

The simulation scenarios are done for the known Pilot Vector  
15 (PV) correlation approach and the Differential Phase Vector (DPV) correlation approach according to the invention. The simulation environment for the comparison is:

- Carrier-frequency mismatch up to 450kHz
- Data modulation scheme QAM16
- 20 • Pilot symbol reference pattern sequence length = 32 pilot symbols
- Pilot symbol pattern sequence length inserted in transmit data stream = 2047
- Symbol rate  $f_s = 9.425\text{MHz}$
- 25 • Pilot Spacing  $PS = 9$
- Pilot symbol amplitude =  $|0.719176 + j0.719176|^2$

Out of these settings follows that the correlation maxima has to be seen at a periodical distance:

$$\text{Period} = PS \cdot \text{TransmitPatternSequenceLength} = 9 \cdot 2047 = 18423$$

(15)

The ideal correlation maxima value has to be in case of PV correlation:

$$|corr_{PV \max}|^2 = 1100, \quad (16)$$

5 and in case of DPV correlation the correlation maxima is:

$$|corr_{DPV \max}|^2 = 1100 \quad (17)$$

Fig. 13 shows the simulation results of the known PV correlation approach with AWGN and an SNR (Signal to Noise Ratio) of 6dB. In case of AWGN the correlation maxima value  
10 changes. With respect to ideal correlation results, the correlation maximum difference between the correlation maxima (n=17128, n=35551) and the other correlation results (n≠17128, n≠35551) decreases in case of noise, but the peaks are well detectable.

15

According to Fig. 13, the maxima are visible at n=17128 and n=35551. Thus, the periodic sequence is detected at the desired positions with constant period. Most important is that the correlation maxima will be seen at the expected positions  
20 and with constant period.

Fig. 14 shows the correlation results for the Differential Phase Vector correlation approach with AWGN and an SNR of 6dB. Compared to the ideal case, the correlation maxima difference  
25 in case of AWGN decreases as in PV correlation case shown in Fig. 13. Nevertheless, the correlation maxima positions as well as the maxima period is given in both cases.

The next simulation scenarios include carrier-frequency mismatch. The expected maximum working range for the Pilot

Vector correlation approach is assumed up to nearly 16 to 18kHz. Simulation results for both approaches with carrier-frequency mismatch and AWGN will be presented up to 450kHz.

- 5 In case of only carrier-frequency mismatch the PV correlation result decreases significantly. Furthermore, as shown in Fig. 15, in case of additional AWGN of SNR=6db the result is decreased again, but is sufficient enough. The maxima positions and period are as expected, and thus the desired  
10 functionality is achieved.

For the DPV correlation approach in case of carrier-frequency mismatch the correlation maxima are the same as in ideal case, as described in connection with equations (4) to (6) above.

- 15 As shown in Fig. 16, the difference from the correlation maxima to other correlation results in case of AWGN at SNR=6dB is decreased. The maxima are at the expected positions and period. The comparison of the simulation results of both approaches shows that the DPV approach delivers the better  
20 performance. The peaks are much better detectable and the frequency error has no impact on the correlation result.

- Fig. 17 shows a simulation result of the PV approach in case of a 21 kHz carrier-frequency mismatch with additional AWGN  
25 with an SNR of 6dB. The correlation maxima are not found at the expected position and period. The simulation result shows that the performance of the PV approach is not efficient enough to find the pilot symbol sequence. The tolerable carrier-frequency mismatch limit is exceeded. A similar  
30 simulation result is achieved without the additional AWGN.

Fig. 18 shows clearly the advantage of the Differential Phase Vector approach according to the invention.

Even in case the carrier-frequency mismatch incredibly increases up to 450kHz, the simulation results of the DPV correlation with and without AWGN show a good performance. The correlation maxima and period are in both cases as expected.

5 The difference from the correlation maxima to the other correlation results is also as expected. So the simulation result confirms the in theory calculated ability of the DPV correlation approach to tolerate higher carrier-frequency mismatches.

10

According to an embodiment, the present invention provides a differential phase vector based pilot sequence synchronization and, thus, pilot detection technique. The technique of the invention has been proved by comparison with the known pilot  
15 vector correlation approach.

Simulations illustrated in Figs. 13 to 18 show the better performance in case of carrier-frequency mismatch and additional AWGN compared to the Pilot Vector approach. The impact of carrier-frequency mismatch has been calculated and  
20 shown by simulations. Because of using the differential phase information the frame synchronization technique is working much better in case of constant frequency errors than conventional techniques. The impact of constant frequency error is completely removed.

25

It is to be understood that the above description is illustrative of the invention and is not to be construed as limiting the invention. Various modifications and applications may occur to those skilled in the art without departing from  
30 the true spirit and scope of the invention as defined by the appended claims.

CLAIMS:

1. A method of synchronizing with a pattern sequence, the method comprising:

5       a first correlation step of correlating symbols of a first pattern sequence, the symbols comprising amplitude and phase information, thereby obtaining a first differential phase information sequence;

10       a second correlation step of correlating symbols of a second pattern sequence, the symbols comprising amplitude and phase information, thereby obtaining a second differential phase information sequence;

15       a third correlation step of correlating the first and second differential phase information sequences, thereby obtaining a correlation result; and

      a step of determining a synchronization between the first and second pattern sequences on the basis of the obtained correlation result.

20   2. The method according to claim 1, wherein

      in the first correlation step a predetermined number  $Z$  of symbols of the first pattern sequence are correlated two at a time;

25       in the second correlation step  $Z$  symbols 1 to  $Z$  of the second pattern sequence are correlated two at a time; and

      the second and third correlation steps are repeated wherein for each repetition  $m$ , in the second correlation step the predetermined number  $Z$  of symbols is shifted by one symbol so that  $Z$  symbols  $1+m$  to  $Z+m$  of the second pattern sequence  
30   are correlated two at a time.

3. The method according to claim 1 or 2, wherein phase information due to a mismatch of frequency information between the symbols of the first pattern sequence and the symbols of

the second pattern sequence is detected on the basis of the correlation result.

4. The method according to any one of claims 1 to 3, wherein  
5 the symbols of the second pattern sequence are contained in a data symbol stream and are modulated in a different way from the data symbols in the data symbol stream, and the method comprises:

10 a step of detecting the symbols of the second pattern sequence in the data symbol stream on the basis of the different modulation.

5. The method according to any one of claims 1 to 4, wherein  
15 the second pattern sequence is received by a receiving device from a transmitting device, and the first pattern sequence forms at least a part of the second pattern sequence and is stored in the receiving device.

6. The method according to any one of claims 1 to 5, wherein  
20 the second pattern sequence is a sequence of IQ pilot symbols which are contained in a received data symbol stream and the first pattern sequence is a reference pattern sequence of IQ pilot symbols.

25 7. The method according to claim 6, wherein the IQ pilot symbols are QPSK modulated symbols, and the IQ pilot symbols of the second pattern sequence are periodically inserted into the data symbol stream at the transmitting device.

30 8. The method according to any one of claims 1 to 5, wherein the second pattern sequence is a training sequence.

9. An apparatus for synchronizing with a pattern sequence,  
the apparatus comprising:

first correlation means for correlating symbols of a first pattern sequence, the symbols comprising amplitude and phase information, and outputting a first differential phase information sequence;

5        second correlation means for correlating symbols of a second pattern sequence, the symbols comprising amplitude and phase information, and outputting a second differential phase information sequence;

10       third correlation means for correlating the first and second differential phase information sequences, and outputting a correlation result; and

means for determining a synchronization between the first and second pattern sequences on the basis of the correlation result.

15

10. The apparatus according to claim 9, wherein

the first correlation means are arranged to correlate a predetermined number  $Z$  of symbols of the first pattern sequence two at a time;

20       the second correlation means are arranged to correlate  $Z$  symbols 1 to  $Z$  of the second pattern sequence two at a time; and

the second and third correlation means are arranged to repeat the correlation operations; the apparatus further  
25 comprising:

shifting means for shifting, for each repetition  $m$ , the predetermined number  $Z$  of symbols in the second correlation means by one symbol so that  $Z$  symbols  $1+m$  to  $Z+m$  of the second pattern sequence are correlated two at a time.

30

11. The apparatus according to claim 9 or 10, further comprising:

means for detecting phase information due to a mismatch of frequency information between the symbols of the first pattern

sequence and the symbols of the second pattern sequence from the correlation result output by the third correlation means.

12. The apparatus according to any one of claims 9 to 11,  
5 further comprising:

storing means for storing the first pattern sequence.

13. The apparatus according to any one of claims 9 to 12,  
further comprising:

10 means for detecting the symbols of the second pattern sequence in a data symbol stream.

14. A system for synchronizing with a pattern sequence, the system comprising:

15 a transmitting device which includes:

means for generating symbols of a pattern sequence to be used for synchronization; and

transmitting means for transmitting the symbols of the pattern sequence;

20 and a receiving device which includes:

first correlation means for correlating symbols of a reference pattern sequence, the symbols comprising amplitude and phase information, and outputting a first differential phase information sequence;

25 receiving means for receiving the symbols of the pattern sequence transmitted by the transmitting device;

second correlation means for correlating the received symbols of the pattern sequence, the symbols comprising amplitude and phase information, and outputting a second  
30 differential phase information sequence;

third correlation means for correlating the first and second differential phase information sequences, and outputting a correlation result; and



means for determining a synchronization between the received and reference pattern sequences on the basis of the correlation result.

5 15. The system according to claim 14, said transmitting device further comprising:

first modulation means for modulating data of the pattern sequence to be used for synchronization, according to a first modulation scheme, thereby providing the symbols of the

10 pattern sequence;

second modulation means for modulating payload data according to a second modulation scheme, thereby providing a data symbol stream; and

15 means for inserting the symbols of the pattern sequence into the data symbol stream.

16. The system according to claim 15, wherein the first modulation means are arranged to modulate the data of the pattern sequence according to QPSK modulation scheme, and the  
20 second modulation means are arranged to modulate the payload data QAM or TCM modulation scheme.

17. The system according to claim 15, wherein the inserting means are arranged to insert the QPSK modulated symbols  
25 periodically into the QAM or TCM modulated data symbol stream.

18. A computer program product, comprising software code portions for performing the steps of any one of claims 1 to 8 when the product is run on a computer.

30

19. The computer program product according to claim 18, wherein said computer program product comprises a computer-readable medium on which said software code portions are stored.

35

20. The computer program product according to claim 18, wherein said computer program product is directly loadable into the internal memory of the computer.

ABSTRACT:

The invention discloses a synchronization with a pattern sequence. In the synchronization, symbols of a first pattern sequence are correlated, the symbols comprising amplitude and phase information, thereby obtaining a first differential phase information sequence, symbols of a second pattern sequence are correlated, the symbols comprising amplitude and phase information, thereby obtaining a second differential phase information sequence, and then the first and second differential phase information sequences are correlated, thereby obtaining a correlation result. Finally, a synchronization between the first and second pattern sequences is determined on the basis of the obtained correlation result.

15

(Fig. 1)



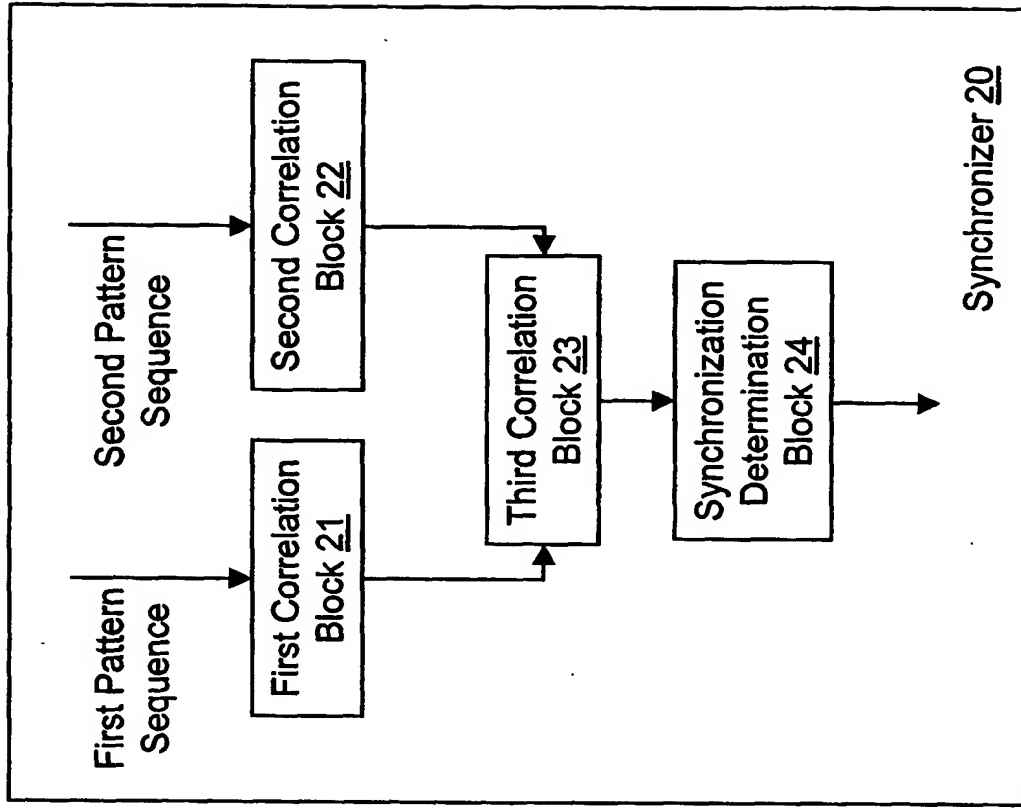


Fig. 2

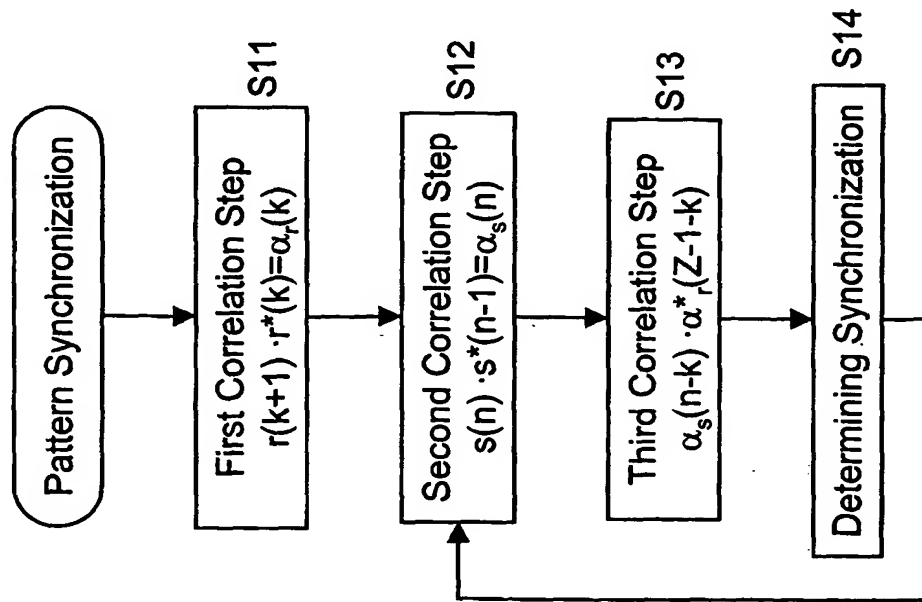


Fig. 1

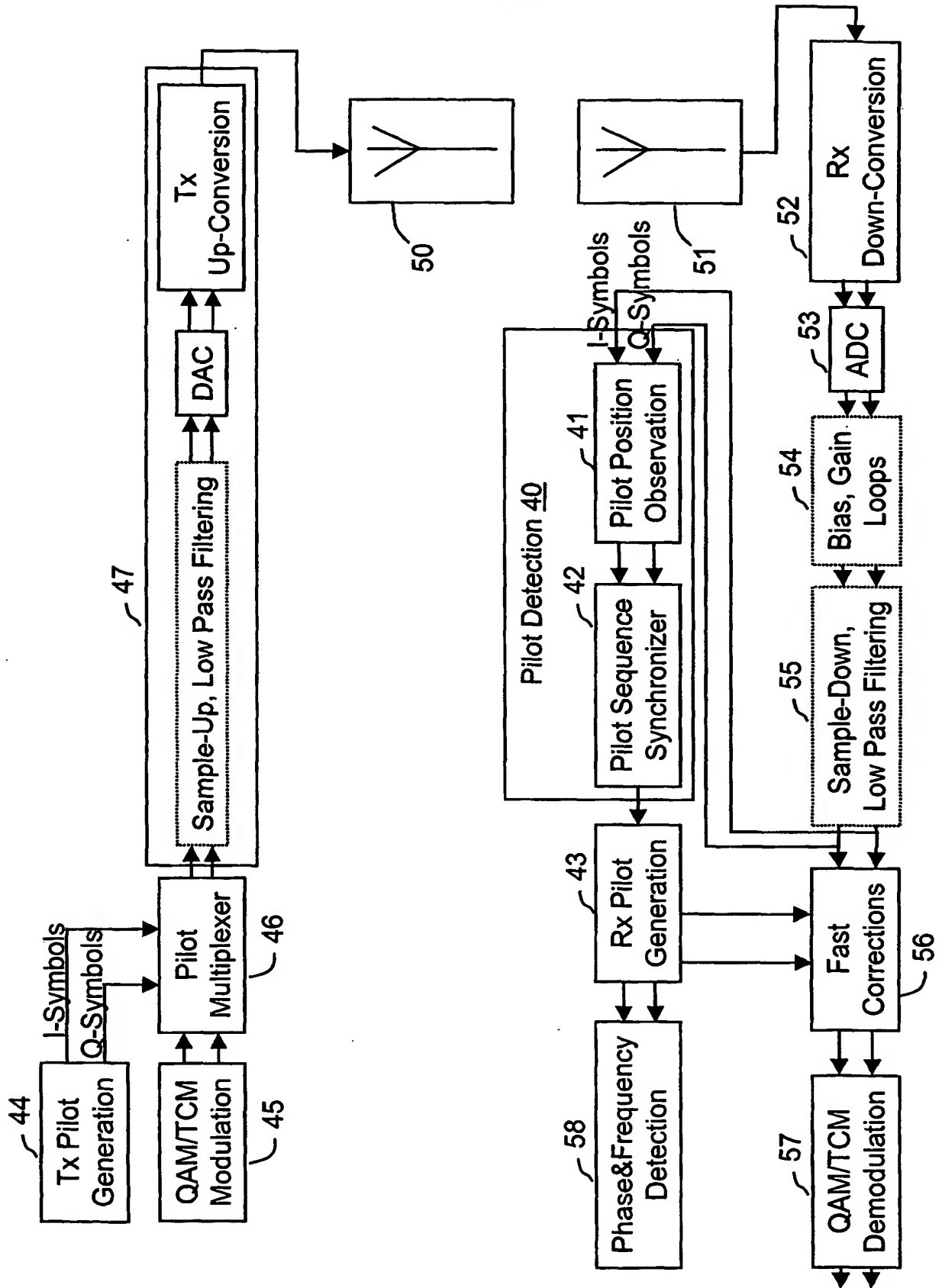
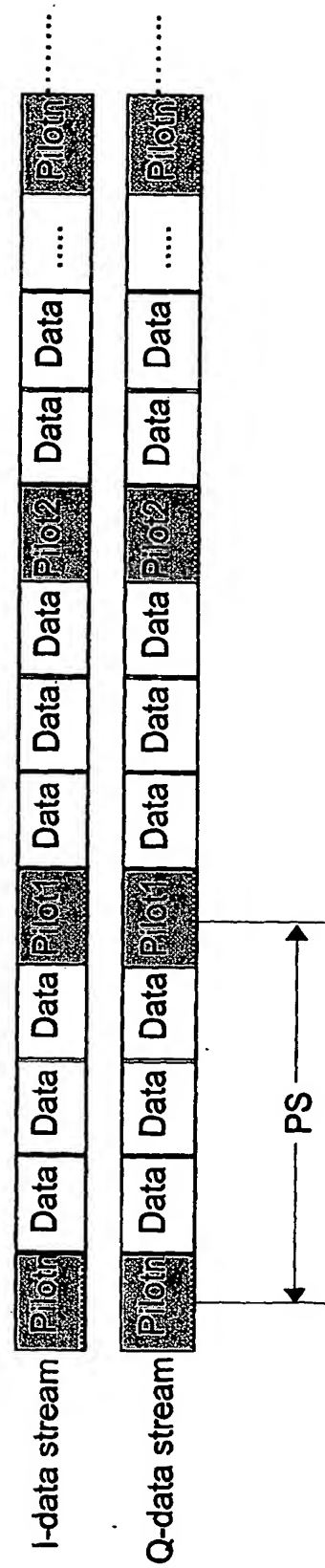
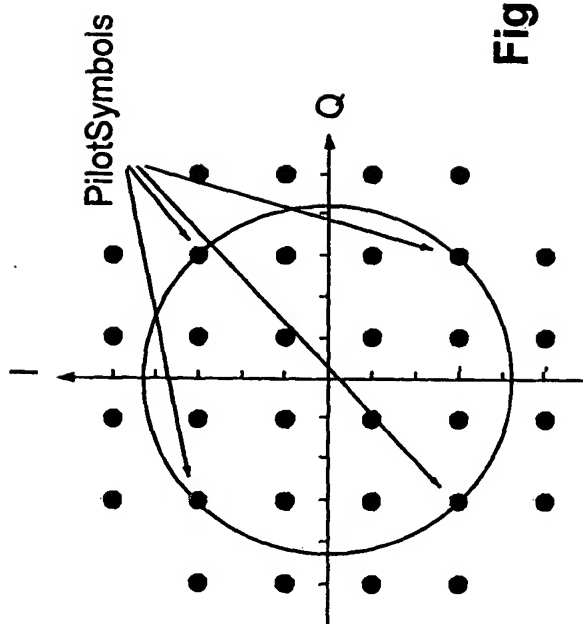


Fig. 3



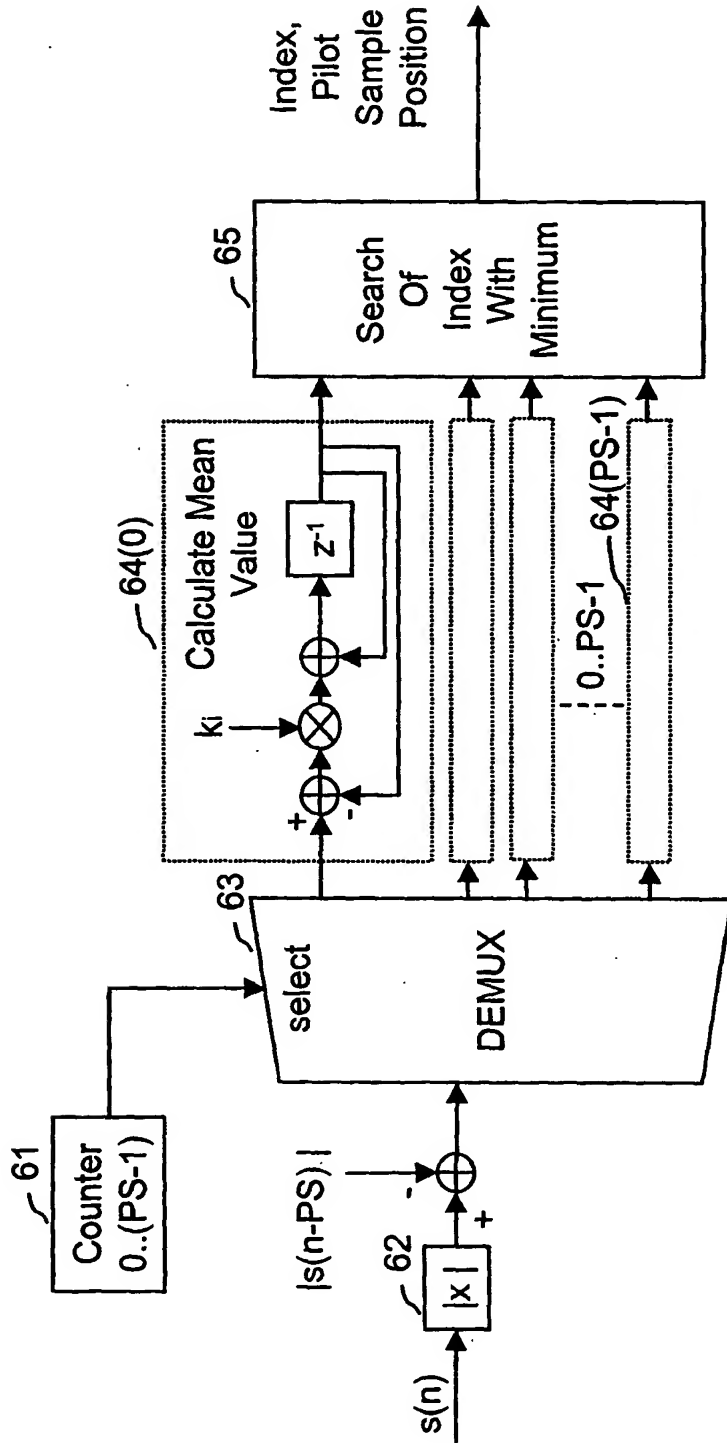


Fig. 6



Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6	Pilot .....	Pilot .....	Pilot R3	Pilot R2	Pilot P-1	Pilot P
------------	------------	------------	------------	------------	------------	----------------	----------------	-------------	-------------	--------------	------------

Complete pattern sequence of pilot symbols  
of length P

Figure 8 consists of two plots. The left plot shows a 2D coordinate system with a vertical axis labeled  $I$  and a horizontal axis labeled  $Q$ . Four points are plotted in the quadrants: two in the upper half ( $I > 0$ ) and two in the lower half ( $I < 0$ ). The right plot shows a similar 2D coordinate system with axes  $I$  and  $Q$ . Three points are plotted in the upper half:  $s(0)$ ,  $s(1)$ , and  $s(2)$ . Dashed lines connect these points to the origin, and curved arrows indicate angles  $\Delta\theta$  between the lines.

**Fig. 9**

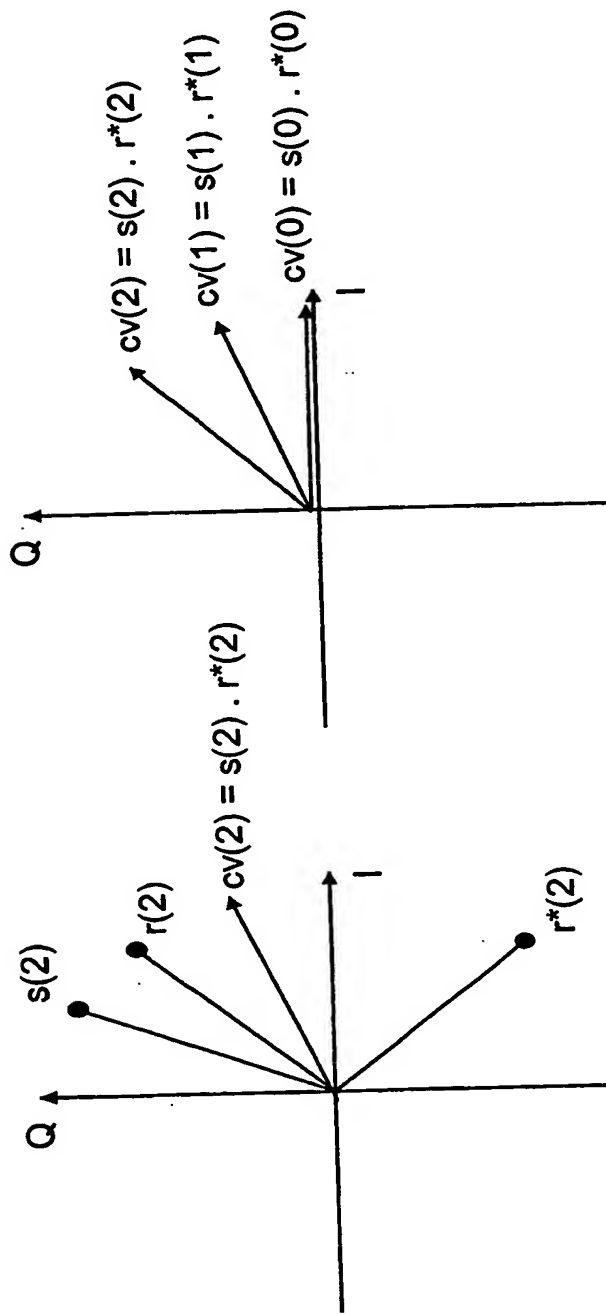


Fig. 10

Fig. 11

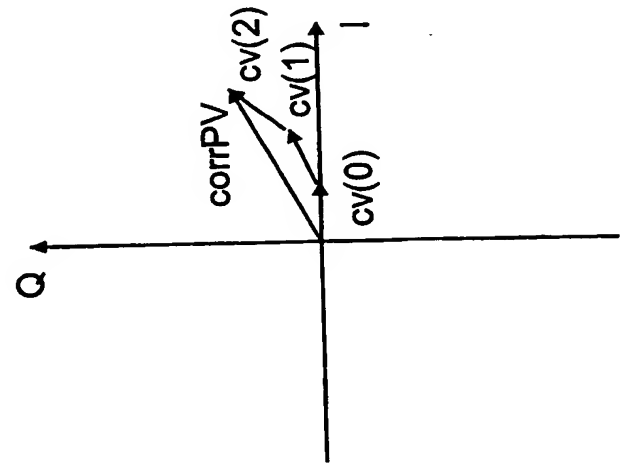


Fig. 12

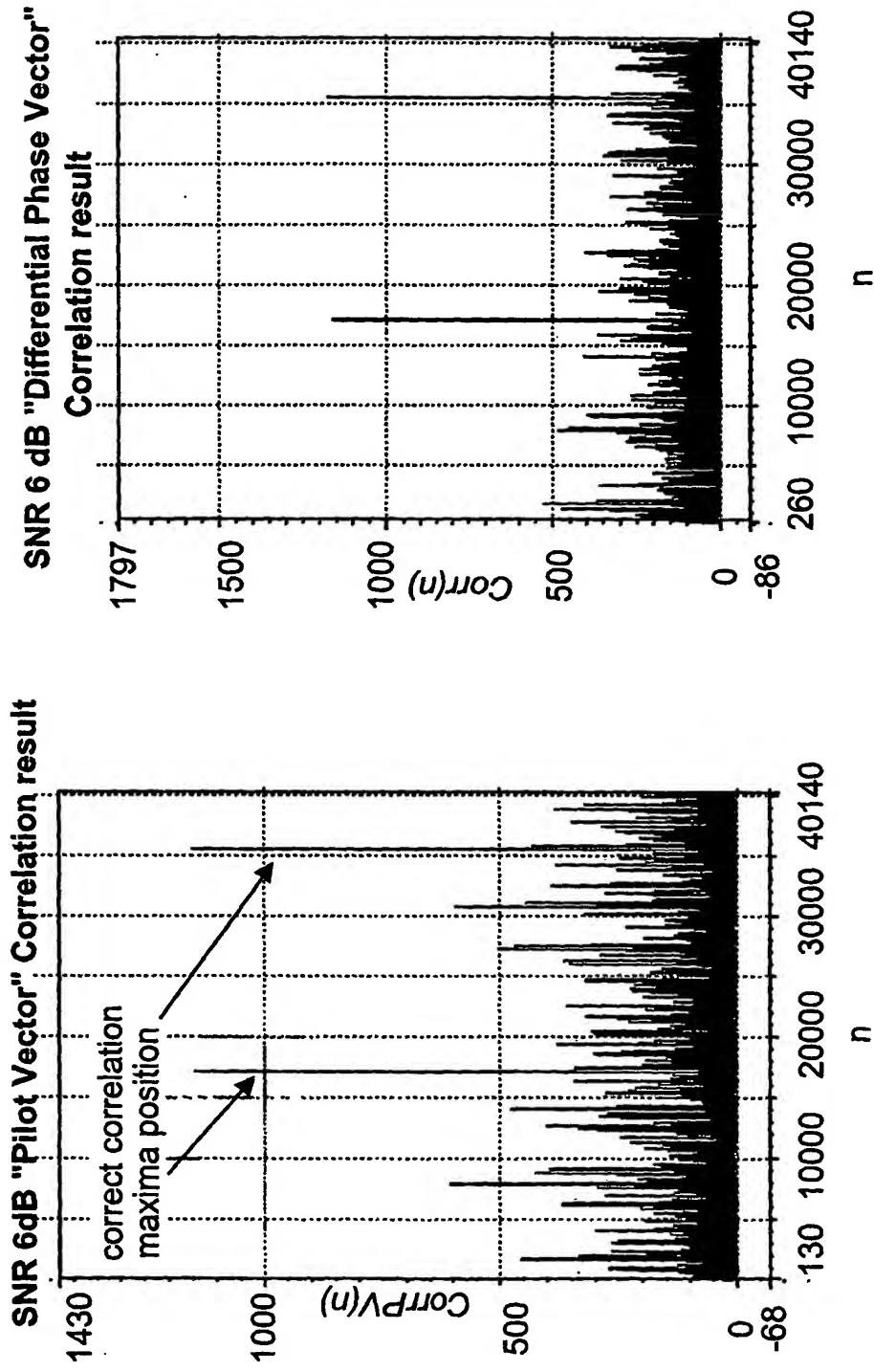


Fig. 13

Fig. 14

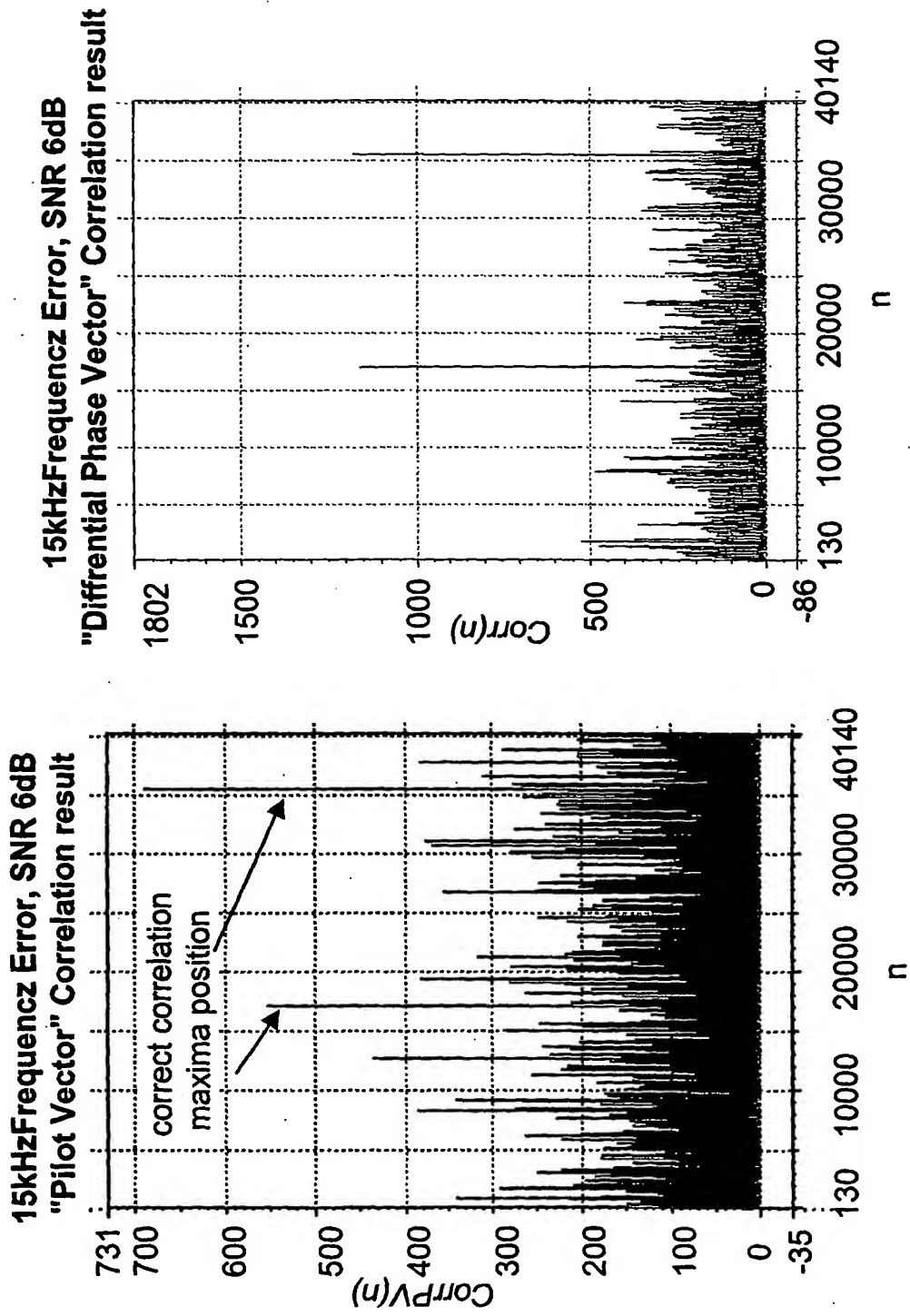


Fig. 16

Fig. 15

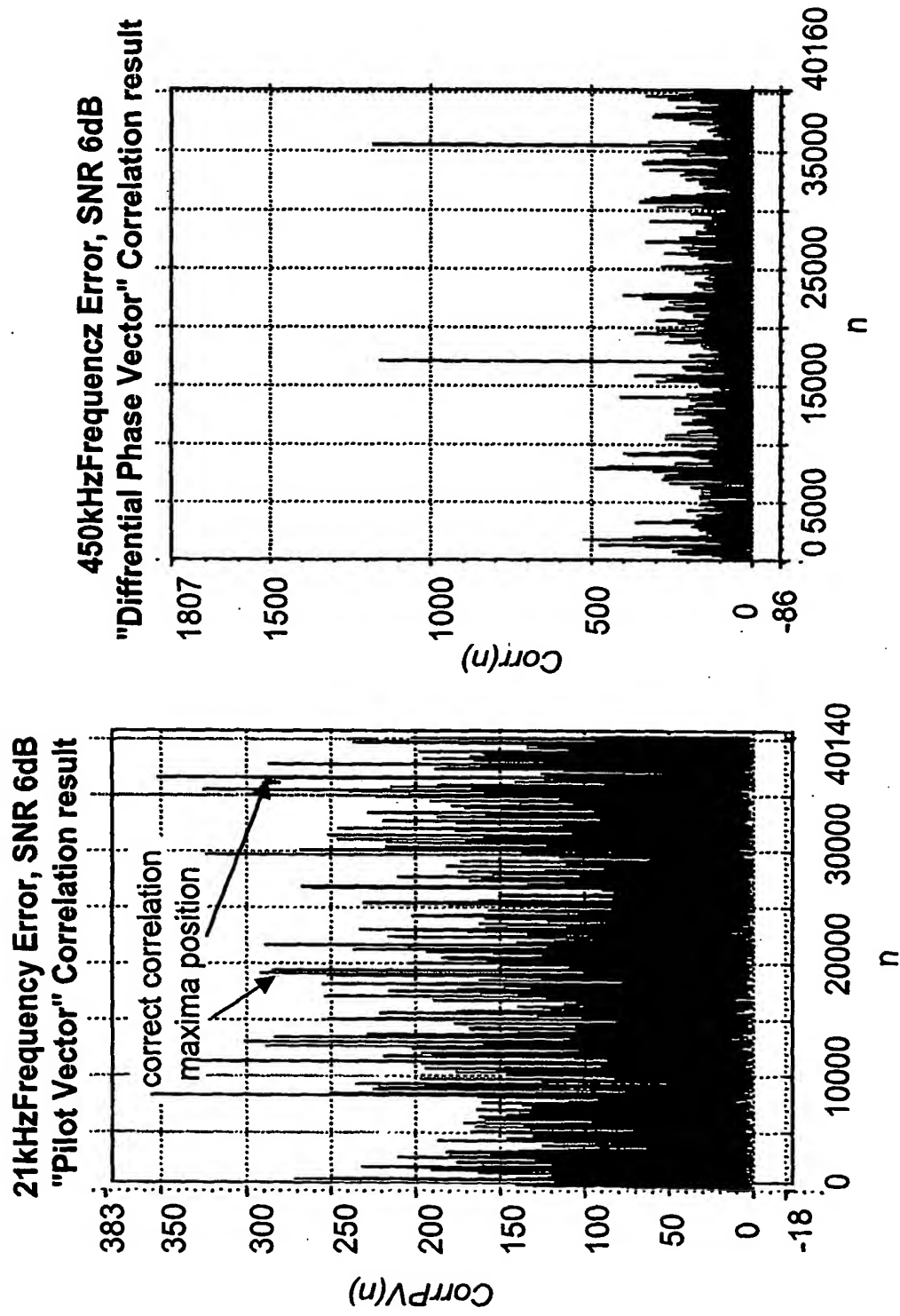


Fig. 17

Fig. 18

